euspen's 18th International Conference & Exhibition, Venice, IT, June 2018
www.euspen.eu

Lateral error compensation for focus variation microscopy

Pablo Pérez[1], Wahyudin P. Syam[2], José Antonio Albajez[1], Jorge Santolaria[1], Richard Leach[2]

[1]Department of Design and Manufacturing Engineering, University of Zaragoza, Calle María de Luna 3, 50018 Zaragoza, Spain
[2]Manufacturing Metrology Team, University of Nottingham, NG8 1BB, UK

pperezm@unizar.es

Abstract
Focus variation microscopy measures both the areal form and areal surface texture of components. Improvements to the accuracy and precision of focus variation microscopes usually requires measurements with multiple image-fields to compensate lateral stage errors. This paper proposes a methodology for compensation of lateral stage error of a focus variation microscope using an uncalibrated artefact.

Error compensation; focus variation; lateral stage performance; kinematic model

1. Introduction

Focus variation microscopy (FVM) combined with multi-axis motion stages is a measuring technique that combines the functionalities of a micro coordinate measurement machine with a surface texture measuring system [1]. Due to these combined functionalities, FVM is widely used for both form and surface texture measurement in industry, research and academic institutions [2,3].

FVM often stitches multiple overlapping images to compensate its lateral stage error, to improve the accuracy and precision of its measurement results. Usually, measurements with multiple image-fields are time consuming and limited by the capacity of the host computer memory to process a large number of images. Nevertheless, users are sometimes often interested in the relationship between geometrical features that are spaced apart by distances that mean they are not in adjacent images.

In this work, a methodology to compensate for the lateral stage error using an uncalibrated artefact is presented. The objective of this method is to be able to compensate the lateral stage error without stitching.

In the following section, the kinematic model of FVM and a procedure to measure the performance of the stage using the proposed uncalibrated artefact are presented. Section 3 contains the results of measurements and the validation of the proposed method. Finally, section 4 presents the conclusions and future work.

2. Methodology

The FVM instrument used is an Alicona G5 Infinite Focus (Figure 1) based at the University of Nottingham. All measurements in this study were carried out by using 5× and 10× magnification objective lenses. The total measuring volume of the FVM instrument was 200 mm × 200 mm × 100 mm.

The methodology to quantify the geometrical errors of the *xy*-stage and to compensate the errors is as follows. Firstly, the kinematic model of the FVM is determined. In the kinematic model, all errors related to the lateral stage of the FVM are considered. The considered errors represent all the components of error that can affect the result of a lateral measurement. Once the kinematic model has been defined, an uncalibrated artefact is measured. The artefact is a metal block consisting of hemispherical ('calotte') features. The artefact is measured twice: with stitching and (in the same position) without stitching. From the measurements, the centre locations of all the calottes are calculated. These centre locations are used in the kinematic model to determine the value of each error component by an optimisation procedure.

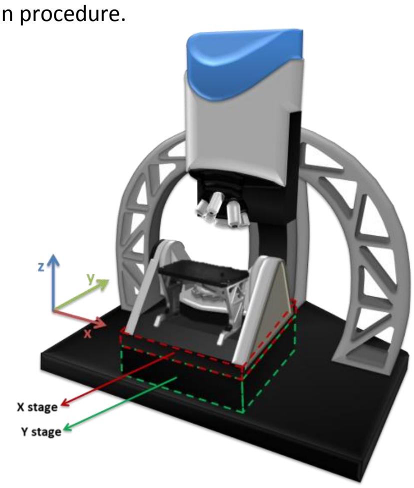


Figure 1. Focus variation microscope and *xy*-stage

2.1. Kinematic model

The proposed kinematic model for the *xy*-stage of the FVM is represented with the following equation:

$$T_P = R_X^{-1}[R_Y^{-1}[T_L - (T_Y + T_{Y0})] - (T_X + T_{X0})] \qquad (1)$$

where T_P are the coordinates of a 3D point without stage errors, T_L contains the *z* (height) ordinate of the measured point, T_X and T_Y are the vectors with the translational errors of *x* and *y* axes,

T_{X0} and T_{Y0} are the offset vectors of the *x* and *y* axes. R_X and R_Y are the matrices representing the rotational errors, thus:

$$R_k = \begin{pmatrix} 1 & -kRz & kRy \\ kRz & 1 & -kRx \\ -kRy & kRx & 1 \end{pmatrix}, \qquad (2)$$

with $k = \{x, y\}$,

$$T_X = \begin{pmatrix} -x + xTx \\ xTy - x \cdot xPy \\ xTz - x \cdot xPz \end{pmatrix}, \qquad (3)$$

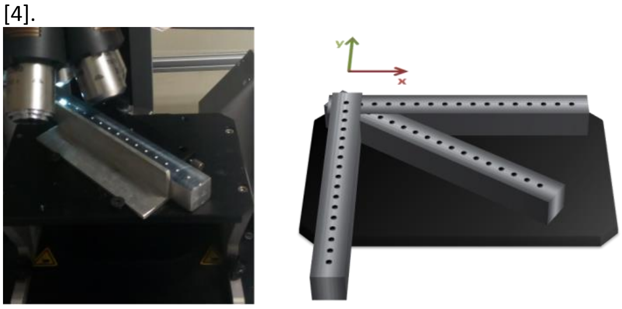
$$T_Y = \begin{pmatrix} yTx \\ -y + yTy \\ yTz - y \cdot yPz \end{pmatrix}, \qquad (4)$$

$$T_L = \begin{pmatrix} 0 \\ 0 \\ z \end{pmatrix}. \qquad (5)$$

With the kinematic model and the measurements of the artefact, with and without stitching, we estimate the kinematic and geometrical errors of the lateral stage needed to compensate a measurement in the lateral direction.

2.2. Artefact

The artefact (Figure 2a) is a linear aluminium block with dimensions of (180 × 18 × 18) mm. The artefact consists of calottes (semi-spherical holes with 2 mm in diameter) having a 10 mm distance between two consecutive centres. The calottes are manufactured by a milling process with a ball-nose tool. The artefact is simple to manufacture. With the uncalibrated artefact, a lateral measurement can be compensated with only few measurement to characterise the lateral stage errors for the compensation. Note that the lateral scale of the FVM must have been already established prior to the procedure presented here [4].



a) b)

Figure 2. a) The uncalibrated artefact used for the error compensation methodology. b) Three positions measured for the kinematic model.

The methodology is implemented by measuring the artefact in different positions (Figure 2b), each position is measured twice; one measurement with stitching and the other one without stitching. The coordinates of the measurement with stitching are introduced in the kinematic model as the T_P vector, while the coordinates without stitching are introduced in the kinematic model as the *x*, *y* and *z* inside the vectors T_X, T_Y and T_L. With the kinematic model, and several calottes measurements with and without stitching, an overconstrained system of equations can be obtained to estimate the lateral stage error and finally compensate a lateral measurement result.

3. Results

Figure 3 shows the values of the geometrical errors of the lateral stage of the FVM obtained from the proposed methodology. A total of fifteen geometric and kinematic errors of the lateral stage have been estimated.

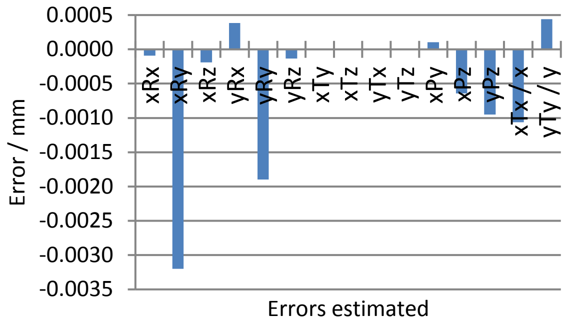


Figure 3. Geometrical errors

With the estimation of the errors, it is possible to perform an error correction of any lateral measurements, where the measurements are carried out without stitching.

The results of the compensation are shown in Figure 4 for ten points measured without stitching with the artefact in a random position over the *xy*-stage. The measurement errors before applying the correction procedure represents the difference between the coordinates with and without stitching and the errors after applying the correction procedure are the difference between the coordinates of the measurement with stitching and those obtained without stitching implementing the error correction.

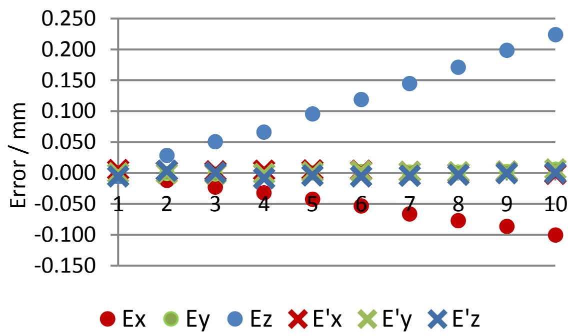


Figure 4. Errors before (Ex, Ey, Ez) and after (E'x, E'y, E'z) the correction

A significant error reduction of the lateral measurements without stitching can be obtained with the proposed error compensation methodology and the uncalibrated artefact.

4. Conclusions

It is possible to characterise the *xy*-stage of a FVM instrument by measuring an uncalibrated artefact. The methodology allows correction of measurements without using image stitching, that will be affected by the stage errors. The errors have been modelled as linear values along the axes and the corrections can significantly reduce the error of lateral measurements. Future work will be to model the errors to take into account non-linearities of the stage.

References

[1] ISO 25178-606: 2015 Geometrical product specification (GPS) — Surface texture: Areal. Part 606: Nominal characteristics of noncontact (focus variation) instruments

[2] Leach R K 2011 *Optical measurement of surface topography* (Springer-Verlag, Berlin)

[3] Moroni G, Syam W , Pretò S 2017 Performance verification of a 4-axis focus variation co-ordinate measuring system. *IEEE Trans. Instrum. Meas.* **66** 113-121

[4] Evans C J, Hocken R J, Estler W T 1996 Self-calibration: reversal, redundancy, error separation, and 'absolute testing' *Ann. CIRP* **45** 617-634